Computer Science: A Demand-Driven Rise to Prominence

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Abstract

Computer Science emerged as an academic discipline largely as a result of the rising demand and pressure for technological innovation during World War II. With clear convictions and an unyielding personality, Howard H. Aiken was one of the major forces behind the field's growth and eventual acceptance into the academic establishment. In 1937 he first proposed the device that would eventually become the Mark I. The United States Navy saw the potentially revolutionary nature of a machine that could assist humans with mathematical operations and funneled large sums of money to stimulate research and development in the field. New military technologies like naval mines, the atomic bomb, and radar relied on computing long and complex mathematical equations, which would have been nearly impossible to tabulate manually. As the demand for these resources continued to grow throughout and after the war, Aiken saw a need to begin systematically training/teaching students in the techniques of computer design, programing, and operation. In 1946 he finally convinced Harvard University to build a laboratory for his team, which quickly became the preeminent center for computer science in the country and an international hub of collaboration for the field. Just a few years later, for the 1947 – 1948 academic year, the university authorized the creation of a degree-granting program in computer science officially and definitively establishing the field as an academic discipline.

Introduction

"... let us begin and create in idea a State; and yet the true creator is necessity, who is the mother of our invention."

The Republic, Book II, Plato

The field of computer science[1] emerged as an academic discipline as a result of the increased demand for computational resources that arose during World War II (WWII). Beginning with his time as a graduate student at Harvard University, Howard H. Aiken was a believer in the utility and necessity of developing large-scale calculating machines that would be able to automate the process of solving complex mathematical problems. In 1937 Aiken partnered with IBM and created the Mark I.[2] It was among the first machines "to be built in order to assist the power of man's brain instead of the strength of his arm."[3] The Mark I was arguably the first large-scale digital computer in the United States and opened the door to an entirely new way of solving problems in mathematics, physics, engineering, and any number of other disciplines. Aiken was a shameless, and very effective, promoter of this technology and

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[1] Neither the terms "computer" nor "computer science" were used in their modern form in the WWII period; they did not adopt their modern definitions until sometime in the late 1950s. The devices that Aiken built were called "calculators" or "computing machines" or some variant thereof. "Computer" still referred to an individual, as in: one who computes numbers using a manual calculator. The discipline was usually grouped in with applied mathematics or engineering or sometimes was referred to as "computational science." Despite the lack of generally accepted terminology to describe the happenings of the field in the 1940s, Aiken and his colleagues were building computers and teaching computer science. For reasons of simplicity and clarity I have used the devices and disciplines modern names throughout. For more information on the terms used to describe this emerging field in the WWII era see Cohen, *Portraits,* 185-187.

[2] The device that was built by Aiken in partnership with IBM was originally known as the IBM Automatic Sequence Controlled Calculator (ASCC). The metal sheath that encases the device is emblazoned with that name to this day. Aiken and Harvard refer to the device as such in many early publications and press releases. However, from the beginning Aiken preferred the name Mark I, although the exact origin of this name cannot be determined except to say it is common practice to name military technology in this way (Mark I, Mark II, Mark III, etc.). When Aiken and IBM had their falling out and the machine was moved to Harvard, Aiken ceased using IBM's name and began referring to it solely as the Mark I. Because this paper is dedicated to the discipline of computer science and not the construction of an individual machine, I have decided for reasons of clarity and simplicity, to refer to it as the Mark I throughout. For more information on the naming of the ASCC/Mark I see Cohen, *Portraits,* xiv-xx.

[3] Hoper, "Aiken and My Favorite Computer," 187.

convinced people across academia, industry, and government that it was worth supporting and deploying.

Through the sheer force of his will Aiken was able to overcome resistance from Harvard's faculty and convince the university to construct the Computation Laboratory at Harvard University (Comp Lab) to house his team and give him a location from which he could expand his field. The United States Navy (USN) became Aiken's primary supporter, commissioning three computers from him over the decade centered around WWII. The Navy supported Aiken's research, helped fund the Comp Lab and its events, and was influential in establishing the academic program in computer science. In no small part because of this support, Aiken was able to establish computational methods as a versatile and valuable tool not only in the military, but also across industries. As the field was growing and its methods were being used by an ever-increasing number of people, Aiken noticed that the number of individuals who were qualified to deploy such methods was quickly running out. As such, once the fervor of WWII began to subside Aiken shifted his focus from developing new computers to training the next generation of computer scientists.

Early History of Computational Devices

Aiken, who always had an eye towards pedagogy, started many of his publications with an overview of the history of computational devices. He opens the first chapter of the *Manual of Operation of the Automatic Sequence Controlled Calculator,* the canonical book on the Mark I, with a quote from English polymath Charles Babbage:

> If, unwarned by my example, any man shall undertake and shall succeed in really constructing an engine embodying in itself the whole of the executive department of mathematical analysis upon different principles or by simpler mathematical means, I have

> no fear of leaving my reputation in his charge, for he alone will be fully able to appreciate the nature of my efforts and the value of their results.[4]

In this chapter he paints a picture of a prehistory of counting machines that dates back thousands of years; Aiken argues that the French Mathematician Blaise Pascal made the first device that could be considered a bona fide adding machine in 1642.[5] He explains that, though Pascal's machine was more akin to modern cash registers than modern computers it was an important milestone in the history of computation as it marked the development of a mechanical device that could perform mathematical operations and output useful answers.[6] In the centuries after Pascal, he continued, many notable scientists including Gregory Gause, James Clerk Maxwell, and Johannes Kepler attempted to create/improve on computation aids. Their efforts were largely for naught until 1812, though, when Babbage set about to construct a difference engine[7] expressly for use by mathematicians and scientists. Though he had some initial success he was not able to expand his design to more robust and useful machines. Aiken believed that his own work on the Mark I was the natural progression of centuries of research and picked up where Babbage's work left off. "Clearly then, Babbage's failure ... was not due to a lack of understanding of the principles and purpose of the engine that he designed, but rather to his lack of machine tools, materials of construction and electronic circuits ... [he needed] the twentieth century and the evolution of advanced mechanical and electrical engineering to bring his ideas into being."[8]

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[4] Charles Babbage, "The life of a Philosopher," quoted in Staff of the Computation Laboratory, "A Manual of Operation," 1.

[5] Staff of the Computation Laboratory, "A Manual of Operation for The Automatic Sequence Controlled Calculator," *The Annals of the Computation Laboratory of Harvard University* 1 (1946): 1.

[6] For more information on the prehistory of calculating machines see Staff of the Computation Laboratory, "A Manual of Operation," 1-9.

[7] A difference engine is a machine that tabulates functions using the mathematical principle of divided differences. It is, in essence, a calculator built to solve only a specific kind of equation.

[8] Staff of the Computation Laboratory, "A Manual of Operation," 7-8,

Through the care Aiken took to establish the historical context in which he was conducting his research or the talks he gave where he discussed the future of computer science it was clear that Aiken had a sense of the importance of the work he was doing.[9] He moved aggressively to bring computational techniques to fields as wide ranging as social sciences and insurance, rightfully believing that despite some initial resistance once the technology was deployed there would be a swift change in perception towards the methodology and field in general.[10] From the outset Aiken had lofty goals for his research and was not shy about sharing—imposing—his beliefs on others.

Howard H. Aiken

I. Bernard Cohen[11] presents Aiken as a "giant of a man," brilliant, quick to judge, and possessing a force of will that allowed him to accomplish things that others could not have dreamed of doing.[12] Despite taking a job installing telephones in the ninth grade, Aiken still managed to be very successful in high school. Upon his graduation and with the help of his superintendent, he enrolled at the University of Wisconsin and took a job at Madison Gas and Electric Company. After college he continued working with public utilities where he developed a strong background in practical electronics and electrical engineering that served him well

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[9] Most of Aiken's important works including the Proposal for the Mark I, his letter to the Harvard Panel on Physics and Engineering, the papers he wrote with Grace Hopper in electrical engineering, and the *Manual of Operation for the ASCC,* opened with a historical introduction to the field. Additionally, Aiken spoke at conferences, wrote, and corresponded widely about the benefits he thought computational techniques could bring to industries as diverse as military research and accounting.

[10] Aiken, "Proposed Mathematical Laboratory," 2.

[11] I. Bernard Cohen received his Ph.D. in History of Science in 1947 from Harvard University. He was a leading faculty member in the department until his retirement in 1984. He is well respected for his research on Isaac Newton. Additionally, his two books, *Howard Aiken: Portrait of a Computer Pioneer* and *Makin' Numbers* are definitive histories of Aiken and the events surrounding the building of the Mark I and the Comp Lab. (The second of which is an edited created with Welch that contain original historical writing and primary sources.)

[12] I. Bernard Cohen, *Howard Aiken: Portrait of a Computer Pioneer* (Cambridge: MIT Press, 1999), 1.

throughout his career. He then did a short stint as a graduate student at University of Chicago. By the time he arrived at Harvard, he was 33 years old, almost a decade older than most other students. He excelled in his studies and completed his thesis on the theory of space charge conduction in 1938 and earned his Ph.D. in physics in 1939. While working on his thesis, though, he ran into difficulty calculating differential equations. He began to work on a machine that would be able to assist in this process by automating much of the tedious and repetitive work involved in solving these types of equations.

Although, as Cohen explains, it is difficult to pinpoint exactly when Aiken first conceived of the device that would become the Mark I, it is clear that in April 1937 he was ready to share his work and move forward with the project that would be the foundation of his life's work. He released a memorandum entitled *Proposed Automatic Calculating Machine* where he laid out the need for large-scale automatic calculator and the technical framework on which it would operate.[13] "The desire to economize time and mental effort in arithmetical computation, and to eliminate human liability to error, is probably as old as the science of arithmetic itself."[14] From the very beginning Aiken saw computational technologies as a way of solving a very practical need not only in the sciences, but also across industries.

Aiken was a perpetual evangelist for the use of computational technology. Cohen discusses how Aiken's role in popularizing the technology with the USN during World War II allowed him to shape the field in its early years. When Aiken passed away in 1973 his official obituary, published by Harvard read, "Aiken was instrumental in bringing to our military R&D programs a scientific discipline that has permitted this nation to maintain its position as a world

[13] Cohen, *Portrait*, 23, 37.
[14] Howard H. Aiken, "Proposed Automatic Calculating Machine," *The Personal Files of Howard H. Aiken*, (Harvard University Archives, 1937): 1.

power."[15] He was able to leverage his dual appointments as a professor at Harvard and a commander in the USNR to promote the use of computational processes and formalize the development of computer science as an academic discipline. He used his influence in the field to establish a program to train the personnel needed to meet the demand for people qualified to operate the large-scale calculating machines that he was helping create.

The Mark I

Aiken set out to find support for his project. Although Harvard endorsed his vision it was not willing to foot the bill, nor did it have the manpower or industrial know how to see it through to completion. Though Aiken argued in his proposal that "... all the [mathematical] operations described ... can be accomplished by ... existing machines when equipped with suitable controls and assembled in sufficient number,"[16] he still found it difficult to convince people of the technological feasibility of his project. After an initial bout of bad luck in securing a corporate benefactor, in 1938 IBM rose to the challenge, partnered with Aiken, and became the primary financial sponsor for the project. They also provided the necessary engineers and technicians to actually construct such a complicated machine.[17] By 1941 when Aiken was called up to active

[15] Cohen, I. B., W. W. Leontif, H. R. Mimmo, A. G. Oettinger, "Howard Hathaway Aiken: A Giant Among Us in Computer Design." *Harvard University Gazette* LXIX.37 (1974): 8.

[16] Aiken, "Proposed Automatic Calculating Machine," 18.

[17] The partnership between Harvard and IBM was complicated, to say the least. After successfully collaborating for years during the construction of the Mark I, their relationship came to head on the eve of the dedication ceremony. Aiken, with Harvard's approval, released a statement to the press greatly downplaying the role IBM had in the Mark I's construction and claimed, what IBM said, was an unfair amount of credit for himself. James Watson, then the president of IBM, threatened to boycott the ceremony. James Conant, then the president of Harvard, rushed to rectify the situation. Ultimately Watson attended and even made an additional $100,000 gift to Harvard for the operation of the Mark I and the expansion of Harvard's computer science program. Despite their efforts to repair the relationship, though, Aiken and Watson/Harvard and IBM could not return their partnership to its former strength and they did not work together again after the initial Mark I project. For more information on the relationship between Harvard and IBM or IBM's early computer (including the Mark I) see Bashe, Charles J., Lyle R. Johnson, John H. Palmer, and Emerson W. Pugh. *IBM's Early Computers*. Cambridge: MIT Press, 1986.

duty in the United States Naval Reserve (USNR) the project was well underway and he handed off day-to-day control of it to his student, Robert Campbell, who saw it through to its completion in 1943 and delivery to Harvard in 1944.

As “technical liaison between Harvard and IBM” Campbell split his time between the IBM facility in Endicott, New York where the Mark I was being assembled and Harvard where he was teaching a “pre-radar” course for Army, Navy and Marine officers.[18] As the Mark I neared completion and the war effort kicked into high gear, though, he began spending more of his time on teaching. This not only established an early precedent for the military’s involvement in courses of instruction at Harvard, which was important when Aiken was looking to establish a program in computer science a few years later, but it also exposed Aiken's team to the intricacies of balancing the demands of academic research, teaching, and military service that came to define his work.[19] Campbell played a key role in strengthening the emerging relationship between Harvard and the military and streamlined the completion and delivery of the Mark I.

On 7 August 1944 the Mark I was officially unveiled to a crowd of VIPs at Harvard. In one of the first comprehensive histories of the digital computer, Paul Ceruzzi argues that it would make sense to choose that date—the day the existence of such machines was made known to the world—as the day that marked the dawn of the computer age.[20] The New York Times wrote “Harvard receives today a device to solve in hours problems taking so much time they have never been worked out.” The Mark I was a marvel of engineering, they continued, “In the completed machine are 500 miles of wire, 3,000,000 wire connections, 3,500 multipole relays

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[18] Robert Campbell, “Aiken’s First Machine: The IBM ASCC/Harvard Mark I,” In *Makin’ Numbers*, ed. I. Bernard Cohen et al., (Cambridge: MIT Press, 1999), 31, 34.
[19] For more information Robert Campbell and his work with the military, Mark I, or Aiken see Campbell, “Aiken’s First Machine,” 31-63.
[20] Paul E. Ceruzzi, *Reckoners: The Prehistory of the Digital Computer, From Relays to the Stored Program Concept, 1935-1945* (Westport: Greenwood Press, 1983), 43.

with 35,000 contacts, 2,225 counters, 1,464 ten-pol switches and tiers of seventy-two adding machines, each with twenty-three significant numbers."[21]

Despite the Mark I's complexity, and much to Aiken's pleasure, it was also extraordinarily accurate and precise. Gregory Welch[22] describes how Aiken programed the Mark I to calculate equations two different ways and compare the results to make sure there were no errors in its calculating machinery. If the answers did not come out exactly the same the Mark I sounded an alarm to alert Aiken or the attending technician of the problem. When he unleashed the Mark I on the task of calculating Bessel functions, he compared the Mark I's results to those manually calculated by other mathematicians and was ecstatic to find that Mark I uncovered errors in their work in the sixteenth and seventeenth decimal places.[23]

Comp Lab

In December 1944 Aiken submitted a report to the Harvard Panel on Physics and Engineering outlining the need for a computer science laboratory. Although the group that Aiken headed existed for many years before they asked for their own building, Aiken argued that without a dedicated space the computer science program could not continue to grow. He explained that the few computer science labs that were already in operation in the United States produced low quality and narrowly focused research. The most prominent mathematical laboratory in the world at the time was at the University of Edinburgh. Even though it was

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[21] "Algebra Machine," *New York Times*

[22] Gregory Welch earned an A.B in History of Science from Harvard University in 1986. He wrote his senior honors thesis, *Computer Scientist Howard Hathaway Aiken: reactionary or visionary?,* under the tutelage of Cohen. For this project Welch conducted many interviews with Aiken's friends, colleagues, and family which were used throughout his as well as Cohen's work. Welch and Cohen later collaborated on and were coeditors of *Makin' Numbers.*

[23] Gregory Welch, "Computer Scientist Howard Hathaway Aiken: reactionary or visionary?" (Honors Thesis, Harvard University, 1986), 50, 52.

equipped with only small key-driven calculators it had managed to expand its area of expertise "to cover nearly all applications to computation in the sciences."[24] However the lack of a large-scale calculator to use for teaching purposes meant that the Edinburgh program could not materially contribute to expanding the pool of individuals who were qualified to work with them. Aiken went on to note "... that the importance of applied mathematics and computations are greatly increasing not only in the engineering and applied sciences, but also in such fields as the social science, commerce, public health, and insurance,"[25] and that if Harvard were to establish "such a laboratory [it] would fill a very real need".[26] Aiken saw an opportunity to use the increased demand for people trained in the design and operation of large-scale calculating machines and the success he had with the Mark I as a way to expand the scale and profile of his research.

Many of the scientific breakthroughs of this era were based on non-linear effects, which meant that in order to turn an equation into a useful solution a very complex differential equation had to be solved. Aiken saw computational methods as the way to alleviate the tedium and inefficiency of computing infinite series[27] and expand the scope of addressable problems across many fields and industries. However, without a large increase in computing resources, the

[24] Howard H. Aiken, "Proposed Mathematical Laboratory," *General Information by and about the Panel on Physics and Engineering*, (Harvard University Archives, 1944), 1.
[25] Aiken, "Proposed Mathematical Laboratory," 2.
[26] Aiken, "Proposed Mathematical Laboratory," 6.
[27] A series is the sum of the all the results obtained from computing a formula or equation over a range of numbers. Finite series have defined first and last terms, whereas infinite series, by definition, are calculated over an unbounded range. Because of this infinite series can only be found (approximated) by adding all the numbers in an infinitely large range together continuously until each subsequent addition no longer materially changes the cumulative answer. Unlike finite series, which although tedious can be worked out manually, infinite series need tools of mechanical analysis in order to yield useful answers. Infinite series, like the Bessel functions the Mark I is notorious for calculating, are widely used across mathematics, physics, computer science, finance, and many other quantitative disciplines.

number of problems whose basic descriptive equations were well known, but could not be solved because of the time it would have taken to manually compute the answer, was building up.

Despite the clear necessity for computer resources that was emerging and Aiken's successes with the Mark I, Harvard's decision to welcome the applied sciences did not come without resistance. Harvard was not willing to authorize the expected $300,000 plus in capital expenses to build the Comp Lab[28] or the over $50,000 (excluding the salaries of tenured faculty) it would cost to run it every year.[29] Cohen explains how Aiken was not one to be easily defeated and took personal responsibility for ensuring the Comp Lab was constructed. He found backing for the project in the form of a $100,000 gift from IBM that came along with the initial dedication of the Mark I, and from $4,000 per month fees the Navy was paying Harvard for the use of the it.[30]

When the Comp Lab was finally approved and built in 1946 it was meant to be one of the first of many buildings in a new “Science City.” The increased demand for applied scientists from WWII stimulated plans for a large complex that would incorporate all of the natural sciences. Though the university seemed to have lofty goals for the Comp Lab, as Cohen continues, the fact that it was physically separated from Jefferson Physical Laboratory, the Physical Research Laboratory, Cruft Laboratory, and Pierce Hall[31] symbolized a disconnect between Aiken’s goals for the program and the University feelings toward applied sciences. Nonetheless, the Comp Lab was built two years after Aiken proposed it, though the rest of the

[28] Irving B. Parkhurst. “Estimated Cost of the Proposed new Computation Building.” *Records of the Computation Laboratory, 1944-1961 (inclusive).* (Harvard University Archives. 1946). 2.
[29] Aiken, “Proposed Mathematical Laboratory,” 11.
[30] Cohen, *Portrait*, 201-202.
[31] Jefferson Physical Laboratory, the Physical Research Laboratory, Cruft Laboratory, and Pierce Hall were the center of Harvard's science and engineering campus when the Comp Lab was built in 1946. All four of these buildings were physically connected by bridges and/or tunnels. At the time of construction the Comp Lab was not connected; however, a bridge was later built to connect it to Pierce Hall.

"Science City" was never built, despite the university having funds for the project and continuing to discuss it for several years.[32] When the Comp Lab opened, Aiken, his team, and the applied sciences more broadly, finally had their own physical location on campus from which to work.

With a physical presence on campus the computer science program underwent a period of expansion. However, throughout this whole period the Navy, and to a lesser extent the Air Force, were the Comp Lab's biggest benefactors and primary beneficiaries of its research. The continued lack of financial support from the University led Aiken to more vigorously court other funding sources. The USN, as was typical for the period, provided the Comp Lab with office furniture and supplies, support personnel, and the money it needed to operate—providing it continued to turn out research that was beneficial to the military. Though the government was largely responsible for funding the construction and continued operation of the Comp Lab the university did not encourage this relationship.[33] As the government got more involved with the funding, operations, and research direction of the Comp Lab, the Harvard faculty became suspicious of Aiken's goals and skeptical of the program's future at Harvard. They instituted rules governing any projects that received government funding, significantly diminishing Aiken's ability to acquire the money he needed to maintain and expand his operation.[34] Despite these

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[32] Gregory W. Welch, "Aiken's Program in a Harvard Setting" In *Makin' Numbers*, ed. I. Bernard Cohen et al., (Cambridge: MIT Press, 1999), 166.

[33] Despite Harvard's early lead in computer science it did not remain at the forefront of the field for long after Aiken retired in 1961. The Massachusetts Institute of Technology and Stanford University encouraged their computer science departments to seek partnerships with the government and industry and integrated applied sciences in general into their pedagogical models. Because of the increased financial and institutional support these computer science departments received they were able to flourish in the second half of the 20th century. Harvard's department, however, without Aiken driving the program forward did not keep pace with changing technology. For more information on the evolution of computer science departments at Harvard, MIT, and Stanford see Cohen, Adam R., "To Discipline Computer Science" Honors Thesis, Harvard University, 1990.

[34] Welch discussed how the faculty of Harvard University was worried that if the government, especially the military, played too large a role in the funding of scientific research they may begin to unduly influence the path of academic research leading to work that was not inline with the university's ethical or pedagogical standards. The faculty placed four restrictions on government funded research: All projects

obstacles, Aiken pushed the program and the university forward and established what quickly became the preeminent computational laboratory in the country.

In addition to the funds the Navy committed to the Comp Lab, the government shuttled seemingly unlimited funds toward research in physics, engineering, mathematics, and life sciences around the country through the Office of Scientific Research and Development (OSRD)[35] during WWII. The sharp uptick in public funding, in addition to its ties to the war effort, brought an increased amount of public attention to the sciences, which historically had received little. This led to a turning point in the perception of science in America and established a tradition of government funding for research that bridged theory and application and led to innovations that could be rapidly deployed to real world problems.

Wartime Technologies

During the war, the military was constantly seeking to develop weapons and other technologies that would give it an advantage over the Axis[36] powers. WWII marked the introduction of a new class of weapons that were built on a backbone of computation. Radar, Long Range Navigation (LORAN), the (atomic bomb) A-bomb, and naval mines were all reliant

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had to align with the academic interests of the department, the university must also sponsor the project, the project had to be based out of university buildings, and the project had to be run by university staff. The faculty thought that these restrictions would give them freedom in their research even if the projects received government support. For more information on how the university restricted/controlled projects that received government support see Welch, "Computer Scientist Howard Hathaway Aiken," 75.

[35] President Franklin Delano Roosevelt established the OSRD by executive order in June 1941. It was created to coordinate all scientific research for the Military during WWII and was headed by Vannevar Bush. In this position Bush held a significant amount of power. He responded directly to Roosevelt and, along with his colleagues, could almost completely control the research priorities of the organization. Given the amount of money at his disposal, over $450 million dollars through November 1955, he was able to shape and direct the direction of scientific research. For more information see Stewart, Irvin. *Organizing Scientific Research for War: The Administrative History of the Office of Scientific Research and Development.* Boston: Little, Brown, 1948.

[36] The Axis was an alliance between Germany, Japan, and Italy during WWII. They fought against the Allies, which was an alliance lead by Britain, the Soviet Union, and the United States.

on large-scale automatic calculators for their design and operation. The war was an engine of innovation and a driving force behind much of the research done at the Comp Lab. Grace Hopper[37] explained how weapons systems in the WWII era were completely transformed by automatic calculation:

> For example, the Navy used new mines that either acoustically or magnetically detected the presence of a ship without direct contact. To deploy them effectively meant calculating the range over which the mines could damage a ship compared to the range at which they could detect it. The results of these calculations told us how far apart to sow the mines. A similar situation pertained with respect to depth charges. Early depth charges were merely rolled off the stern of a destroyer. The new ones introduced during the war were propelled by rockets. The question was where should they go and in what pattern should they be fired. Again, computations were required to find the answer...[38]

Not surprisingly, the Navy thought very highly of Aiken and his team. Rear Admiral C. T. Joy of the USN[39] remarked "...that although the Navy may have contributed, by material support and encouragement, some of the 'tissue' of this marvelous mechanical 'brain,' Professor Aiken and his staff must be given full credit for having supplied the 'gray' matter."[40] The increased urgency and importance placed on scientific research by the government at the time allowed Aiken and other researchers like him to make a big impact on how the military developed and deployed weapons. Welch argues that even though technically Aiken carried out the orders that were

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[37] Grace Hopper was a Lieutenant in the USN who joined Aiken's team at the Comp Lab in 1944. Along with Ensign Robert Campbell and Ensign Richard Bloch, Hopper was among the first computer programmers. She went on to develop the Common Business-Oriented Language (COBOL) programing language and invent the compiler. She is also credited with popularizing the term "debugging" in reference to fixing computer glitches after finding an actual moth interfering with a relay tube in the Mark II. For more information see United States Navy. "Rear Admiral Grace Murray Hopper, USN 9 December 1906 - 1 January 1992" *Biographies in Naval History*. Accessed November 16, 2013. http://www.history.navy.mil/bios/hopper_grace.htm

[38] Grace Hopper, "Aiken and My Favorite Computer" In *Makin' Numbers*, ed. I. Bernard Cohen et al., (Cambridge: MIT Press, 1999), 186.

[39] Rear Admiral C. T. Joy was commanding officer of the Naval Proving Grounds in Dahlgren, Virginia and the official representative of the Bureau of Ordnance at the Symposium. The Bureau of Ordnance sponsored the Symposium and much of the work at the Comp Lab. Additionally, the Naval Proving Grounds was responsible for contracting Aiken to build the Mark II.

[40] Staff of the Computation Laboratory, "Proceedings of a Symposium on Large-Scale Digital Calculating Machinery, 7-10 January 1947," *The Annals of the Computation Laboratory of Harvard University* 16 (1948): 4.

handed down to him by his superior officers in respect to what research the Navy should focus on, in reality he was actually more of a partner in the decision making process and helped guide the Navy in its development and use of computational resources.[41]

During the war the Mark I was monopolized by the Navy. It spent most of its time working through differential equations that would have otherwise taken humans a prohibitive amount of time to solve. It churned out volumes of tables of highly accurate and precise results that could then be utilized to optimize the design of ships, create firing tables for heavy artillery, or any number of other applications in applied mathematics.

The demand for these tables and computational resources in general was so great that the Mark I was kept running 24 hours a day.[42] Aiken had a team of enlisted Navy "I-Specialists"[43] under his command to keep constant watch over the Mark I and make sure it was operating smoothly.[44] Additionally, the Mark I required at least four fully trained mathematicians to create problems for it and interpret the results. Cohen argues that Aiken was highly skeptical about the ability to maintain a pool of qualified people to program large-scale computing machines. Aiken's concerns seemed largely founded as during WWII the number of calculating machines

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[41] Welch, "Computer Scientist Howard Hathaway Aiken," 47.

[42] Although the Mark I is recognized as the first large-scale automatic computer it was not all alone in the field. Other machines were built to assist with the war effort. Of particular importance is the ENIAC. The ENIAC was an early computer that was announced in 1946 and built at University of Pennsylvania's Moore School of Electrical Engineering. It was built for the sole purpose of solving differential equations for the United States Army's Ballistic Research Laboratory. Even though the ENIAC was built after than the Mark I some credited it with ushering in the computer age. This is a difficult determination to make and is highly dependent on the frame of reference (e.g. architecture, design, operation) that is used. Both machines have their supporters and detractors, but the question as to which one is the true archetype to modern computers is not cut and dry. The ENIAC was initially built as a plug-board machine, only capable of simulating a single problem (its programmable features were added later), whereas the Mark I was always automatically sequenced, which more closely resembles the characteristic of modern computers. For more information see Ceruzzi, *Reckoners*, 105-130.

[43] In this case the "I" denotes the letter, not the Roman numeral. These men were trained in the use of IBM equipment. The designation had nothing to do with the fact that Aiken referred to his machine as the Mark I.

[44] Richard Bloch, "Reminiscence of Aiken during World War II and Later" In *Makin' Numbers*, ed. I. Bernard Cohen et al., (Cambridge: MIT Press, 1999), 196.

steadily increased, while the number of doctorates in mathematics did not. At this rate, 25 machines would have required well over 100 people to reliably run and maintain. However, this far exceeded the number of mathematicians in the country who were capable of doing such work as in the years preceding WWII very few doctoral degrees in mathematics were awarded.[45] Aiken saw that technological advancement was stagnating not because of lack of inspiration, but because of the lack of computer resources necessary to solve the equations that would turn those inspirations into actionable technologies.

Through the entire process of solving problems for the Navy, Aiken always had an eye on the "teachability" of his research. Welch explains that, despite the staggering amount of work Aiken and his team had, he always made sure the programs that were written for the Mark I were fully documented.[46] The fact that most of the programs would never be seen or even used by anyone outside of the Comp Lab because they were "hardly completed before the code book was out of date"[47] was not important to Aiken.[48] By instilling good design practices in his team they were well prepared to explain their processes, methodology, and research to others—who may not be as knowledgeable or technically proficient as they were—which was extremely useful as their focus shifted to education in the post war era.[49]

A Change in Focus

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[45] Cohen, *Portrait*, 186.
[46] Welch, "Computer Scientist Howard Hathaway Aiken," 49.
[47] Staff of the Computation Laboratory, "A Manual of Operation," iii.
[48] In addition to becoming quickly outdated, much of the work was classified as result of it being done under military contracts and, therefore, could not have been shared even if Aiken wanted to.
[49] The belief behind producing well documented code is that anyone, (nearly) regardless of technical proficiency should be able to examine the documentation and determine how to use a specific program. This practice is still central to computer science, especially among open source and collaborative projects which are especially popular among "do it yourself (DIY)" and educational communities.

As Aiken became increasingly focused on his educational goals it made sense that he grew weary of the secrecy that was imposed on his work by the military. In 1946 Aiken's desire to disseminate and share his work surfaced when he ordered Hopper to write the *Manual of Operation for the Automatic Sequence controlled Calculator*. It contained extremely detailed schematics of the Mark I as well as sample programs that could be run on the Mark I and a selection of problems that it had solved. Hopper notes that, "[w]ith the *Manual* you could assemble Mark I all over again, if you felt like it."[50] Furthermore, and in line with his educational aspirations, it opened with a chapter on the history of computational technology that focused on why and how this technology had been used in the past, while alluding to how it should be used in the future. Both Babbage and Aiken saw no reason why machines should not assist people with mental endeavors as they had with physical ones[51] and Aiken believed that computational methods would revolutionize fields as far ranging as public utilities and insurance.[52] The *Manual of Operation* was much awaited by the computer science community and both directly and indirectly led to an increase in the availability of resources on computational sciences.

After the war was over Aiken resisted projects that he could not share or use to further the educational mission that he saw as increasingly important to the survival and expansion of the Comp Lab at Harvard and computer science in general.[53] Aiken noted in a memorandum on the state of the Comp Lab in 1947 that, "the present writer is unwilling to undertake 'classified'

[50] Hopper, "Aiken and My Favorite Computer," 191.
[51] Staff of the Computation Laboratory, "A Manual of Operation," 6.
[52] Welch, "Aiken's Program," 172.
[53] Aiken asserts that the Navy and Air Force were largely accepting of his position, though he did note that the contract to do work with the Atomic Energy Commission was in doubt at the time he wrote the memorandum because of his stance on the free flow of information. Cohen explains that Aiken's resistance to conducting classified research eventually prompted Harvard to adopt a similar position against such projects across the university. Nevertheless the military remained intimately involved with Aiken and computer science research in general. To see a reproduction of the memorandum and/or for more information on Aiken's beliefs relating to the flow of information see Cohen, *Portrait*, 263-268

work in the Computation Laboratory since such work is in large part inconsistent with the very purpose for which the University exists."[54] With his shifting focus and in an effort to increase collaboration and awareness in the field Aiken welcomed researchers from around the globe and across industry. People visited the Comp Lab from Sweden, India, Czechoslovakia, and General Electric Company, among many other places/institutions.[55] Aiken was enthusiastic about sharing his and his team's work. As the constant pressure from the military wound down in the post-war era "channels of communication" were "re-established" throughout the field.[56] With the flow of information increasing Aiken seized the opportunity to focus on spreading and popularizing computational methods and furthering research and education in the new field of computer science he was helping to create.

Symposium on Large-Scale Digital Calculating Machinery

As the importance of computation grew and in the spirit of collaboration, Aiken felt that there was a need to bring together the leading minds in the field under one roof. The field was experiencing growing pains because it was expanding so rapidly. Issues like the lack of a seminal journal began to become serious problems. Aiken recognized that the lack of communication within the discipline was causing researchers to unnecessarily duplicate one another efforts and was slowing the speed of technological advancement. So in January 1947 he organized, with the help and support of the university and the Navy, the Symposium on Large-Scale Digital Calculating Machinery to be held at the Comp Lab. Over three hundred people from around the

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[54] Howard H. Aiken, "Memorandum on the Computation Laboratory," *Records of the Computation Laboratory, 1944-1961 (inclusive),* (Harvard University Archives, 1946). 4.
[55] Aiken, "Memorandum," 2.
[56] Staff of the Computation Laboratory, "Proceedings," 277.

United States and the world attended, far more than Aiken had originally anticipated.[57] Over the course of four days the leaders in the emerging field of computer science discussed a range of topics from the most technical issues, involving the design and underlying mathematical principles of large-scale calculators, to how this new technology could be applied to military, industrial, and social problems.[58]

In addition to discussions on military topics, which mostly focused around how best to leverage computational methods to answer question in ship design and ballistics, Aiken also invited—encouraged—conversation on non-military applications. The Harvard Economist Wassily Leontief had been working with Aiken to use the Mark I to compute a solution to a complex system of differential equations that modeled the flow of income through whole economic systems. Leontief may have been the first person to apply computational methods to the social sciences and Aiken was eager to have him share his experiences at the symposium in order to broaden the scope of the discussion. With WWII and much of the classification of data and methods that came along with it over, attendees spent their four days at the Comp Lab swapping information with other researchers and charting a course for the future of their discipline as it diverged from its military foundation.

Rear Admiral Joy offered one of the opening speeches at the symposium. He began with an anecdote about a recent trip he had taken to Shanghai, China to meet with his counterpart in the Chinese Navy. He was showing off his new heavy cruiser, the *St. Paul*, which was equipped with the latest and most advanced technology like radar, remote controlled guns, blind-firing gun detectors, and other "devices which were almost unheard-of at the beginning of the war."[59] The

57 Staff of the Computation Laboratory, "Proceedings," 7.
58 In 1973 Leontief won the Nobel Memorial Prize in Economic Sciences for this work. For more information see Cohen, Portrait, 205-207.
59 Staff of the Computation Laboratory, "Proceedings," 4.

Chinese Admiral, trying to save face because his fleet was antiquated by comparison, asked if he understood any of the new technology. Joy conceded that he did not, but said that nonetheless "these modern tools of warfare which American scientists have given us" provide "inestimable value" to the Navy. He continued to explain how despite the complexity of the techniques and the seeming culture clash between the Navy personnel at the Proving Grounds[60] and scientists responsible for developing these technologies at universities, "we can at least appreciate what" high-speed calculating machines "mean to the Navy in advancing our knowledge of the science of naval gunnery."[61]

Samuel H. Caldwell[62] declared in his address that "From a cold start in 1940 he labored in every phase of war science until, by 1945 he had demonstrated that mathematical computation was a part of the backbone of military strength."[63] The prominence and importance of computer science had risen markedly as a result of the war. The "wartime mathematicians" were an integral part of America's national defense and demonstrated the need for the military to increase its computational prowess in order to maintain comparative and strategic advantages over possible foes.

Despite computer science's rapid expansion, Caldwell continued, "[w]e still cannot find enough men who are qualified to carry out this work..."[64] Unlike many other fields that

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[60] Proving Grounds is the military designation for any base or installation that is primarily concerned with testing and developing news weapons or combat tactics.
[61] Staff of the Computation Laboratory, "Proceedings," 4.
[62] Samuel H. Caldwell was an associate professor of electrical engineering at MIT. He played a key role in their computer science program during the war and served on the NDRC, which operated under the umbrella of the OSDR. For more information on Caldwell or wartime computer science research at MIT see Aspray, William. "Was Early Entry a Competitive Advantage?: US Universities That Entered Computing in the 1940s," *IEEE Annals of the History of Computing* (2000): 42 - 87.
[63] Staff of the Computation Laboratory, "Proceedings," 278. In this quote, taken from a speech Caldwell gave at the Symposium on Large-Scale Digital Calculating Machinery held at the Comp Lab in 1947, "he" is referring to all mathematicians and scientists in general, who participated in research for or funded by the military during WWII.
[64] Staff of the Computation Laboratory, "Proceedings," 278.

flourished during WWII computer science continued to grow rapidly even after the war was over. Even though it continued to be largely supported by the government after the war, there was increasing participation by industry and other scientists.[65] Fields such as physics and chemistry, although crucial to defense research, only had limited appeal on a broader industrial level and therefore were not as in demand after the end of WWII. Computer science, on the other hand, was just expanding from its academic and military activities. As computer resources were freed from government use, companies/industries experimented with them and came to fully understand their potential. As a result, even though wartime scientists were being released from duty, the growing demand for computer scientists from industry exacerbated the supply problem and was more than able to absorb veterans into the workforce. With the computational sciences firmly ingrained in many fields and beginning to expand horizontally it became clear that if no action were taken it was only a matter of time before demand for computational resources would far outstripped supply.[66]

On January 10, the last day of the symposium, Aiken addressed the issue of personnel development within the field of computer science:

> It has become increasingly clear that we must start a training program. We must remember that our universities are primarily institutions for the building of men and not for the building of machines, and we must offer courses of instruction in this field. I feel that one of the most important contributions that the Staff of this Laboratory can now make is, with the coming of the next school year, to offer courses of instruction in applied mathematics with a strong flavor of computing machinery. I sincerely hope that, with the permission of the Faculty of this University, we shall find and develop methods of furthering this purpose.[67]

The news was sensational. It was picked up by Newsweek Magazine who wrote “It was almost as if Henry Ford had in the early 1900s told his fellow automobile manufactures that he

[65] Staff of the Computation Laboratory, “Proceedings,” 277.
[66] Staff of the Computation Laboratory, “Proceedings,” 283.
[67] Staff of the Computation Laboratory, “Proceedings,” 302.

would never make another car but would spend his the rest of his life on traffic safety problems..."[68] However, the announcement was far more important and less dramatic than the popular press made it out to be. Aiken's speech marked an important shift in his beliefs about the proper direction for the future of computer science. Cohen argues that Aiken's most significant contribution to computer science may not have been the building of the Mark I or its successors, but rather the establishment of computer science as an academic discipline. The next academic year, Harvard University created a program in computer science. The inauguration of the program represented a culmination of the rapid and continuous changes that the field had experienced in the decade since Aiken first proposed building the Mark I in 1937.[69]

A Program in Pure and Applied Physical Sciences

Aiken faced a non-trivial amount of resistance on his path to legitimize computational research. Yet, he saw an opportunity for Harvard to raise its profile as a center for applied sciences and he convinced the administration to, at least temporarily, back his vision. Part of the conflict was centered around the reality that in the years before and even during the war, science, especially applied sciences, were not considered as prestigious as humanities or social sciences as they were thought to be out of step with Harvard's liberal arts based pedagogical philosophies. By the end of WWII, though, as Welch argues, the overwhelming success of new technologies such as radar and the A-bomb lifted the status and profile of applied science.[70] Scientists and their research were on the front page of popular magazines and newspapers and the public became aware of the impact science was having on their lives. The program launched with the goal of combining "the interests of the branches of engineering and physical sciences" in hopes

[68] "Revolutions in Robotland," 58.
[69] Howard H. Aiken, "Proposed Automatic Calculating Machine," 1.
[70] Welch, "Computer Scientist Howard Hathaway Aiken," 70.

that "Harvard would ... be one of the foremost institutions in this field of engineering and would acquire, in the course of years, a reputation in the physical sciences equivalent to the reputation which Harvard already has in law and medicine."[71] With the construction of the Comp Lab in 1946 computer science became a part of the academic landscape at Harvard.

In 1947 - 1948, its first academic year, it offered courses for students seeking both bachelor's and master's degrees.[72] The coursework was very much focused on applied math and was anchored by Aiken's course: Applied Science 218 on "the organization of large-scale calculating machinery." The availability of the Mark I to teach on and the prominence of the Comp Lab's researchers made Harvard an ideal institution to begin systematically training the next generation of computer scientists.

As was typical in this period, the government played a key role in the establishment of this program. The government was commissioning computers as quickly as it could and as it vastly expanded its amount of available computing resources it needed to find a way to expand the number of people who could operate them in step. Through an arrangement with Harvard in which they provided financial support[73] for the program, the Navy was able to select half of the 30 individuals who were in the program, provided they met the Harvard's admission requirements. Harvard selected the remaining 15 candidates independently.[74] Despite the fact that Aiken retired from the USNR in 1946 at the conclusion of WWII many of his team members,

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[71] Howard H. Aiken, "A Program in Pure and Applied Physical Sciences," General Information by and about the Panel on Physics and Engineering, (Harvard University Archives, 1944).
[72] The Harvard Program would introduce a Ph.D. program in 1948 - 1949 academic year, the first program in the country to do so. For more information see Cohen, *Portrait*, 185-187.
[73] Financial support for the computer science program was ultimately taken over by the Air Force in a deal that lead to Aiken training Air force personnel and designing and building the Mark IV for its use.
[74] Cohen, *Portrait*, 187.

including Hopper, and much of the staff of the Comp Lab remained enlisted[75] and military research remained central to the work done at the Comp Lab.

It should be noted that Columbia University actually offered courses in computational sciences the academic year before they were offered at Harvard. However, In 1947 very few institutions—Columbia included—had hardware that was comparable to what was available at Harvard and, as such, their program of instruction was not on par with what was offered at Harvard just a year later. As Aiken wrote to the Harvard Panel on Physics and Engineering, any students that went through this program would be adequately prepared to enter any number of fields that utilized numerical and computational techniques, which could not be said for the Columbia program. Because of the Comp Lab's resources and its ties to the military, which was a driving force behind much of the innovation in computer science that occurred in the 1940s, when it offered courses for the first time in 1947 it more definitively marked the emergence of computer science as an academic discipline. Aiken hoped that with the inauguration of this program he would be able to provide significant relief to the overextended pool of computer scientists.

Conclusion

WWII fundamentally changed the way the military approached scientific research. The formation of the OSRD in 1941 signaled the government's intent to use its money to influence the path of science in an effort to spur the development of technologies that could readily and rapidly be deployed to the battlefield. Projects such as the development of the A-bomb, radar, and naval mines, among many others, demonstrated the amount of capital the government was willing to invest in scientific research in hopes of developing ever more advanced weapons.

[75] Cohen, *Portrait*, 161, 201

Aiken capitalized on this increase in military support to expand the prominence and prestige of computer science at Harvard and around the world.

The Comp Lab was built in 1944 with major support from the Navy and marked a new acceptance of applied sciences at Harvard. The faculty was skeptical of Aiken and applied sciences from the outset and as time went on and the war wound down it only got worse as their concerns about the government's role in science and the applied sciences in general grew. A perpetual supporter of using scientific techniques—specifically computational ones—to solve real world problems, Aiken refused to shy away from or slow down his promotion of computer science and the Comp Lab. At the end of the war, though, Aiken decided to resign from the USNR and shift the focus of his work from helping to develop new weapon systems to education and spreading computer science as widely as he could. At the Symposium on Large-Scale Digital Calculating Machinery in January 1947, Aiken announced his intent to stop designing and building large-scale calculators and instead focus on instruction with the creation of courses in "applied mathematics with a strong flavor of computing machinery."[76]

In large part because of Aiken's leadership, in the 1947 - 1948 academic year Harvard offered its first classes in computer science. After the program's second year Aiken wrote in a memorandum on the state of the Comp Lab that "seventy-six students have enrolled in this program, at least part time. Fourteen M.S. degrees and one Ph.D. have been given."[77] The new program helped bolster the ranks of computer scientists and alleviate the demand strain that had been placed on them throughout the war. Because of the expertise of its personnel and the availability of a large-scale calculating machine to teach on, Harvard quickly established itself as the premier institution in the United States, arguably the world, to teach computer science in a

[76] Staff of the Computation Laboratory, "Proceedings," 302.
[77] Aiken, "Memorandum," 3.

formal setting. Caldwell explained that "Although a substantial nucleus of knowledge in this field existed before the war, and although much of the wartime program was based on this earlier art, we must, nevertheless, recognize the tremendous impetus given to the work by the needs of war."[78] For a field that barely existed at the beginning of the decade, such a rapid rise to prominence is indicative of the societal and scientific changes brought on by WWII.

Aiken was able to leverage his post in the USNR and his professorship at Harvard to popularize the practice of turning to computational methods for military, scientific, and industrial problems. Aiken knew he would need to establish a training program if he wanted computer science to continue to grow. It was under these conditions—the confluence of the rising demand for computational resources, the newfound prominence of applied sciences, and his own grit and determination—that Aiken was able to create a highly respected facility for computer science at Harvard and formalize computer science as an academic discipline.[79]

[78] Staff of the Computation Laboratory, "Proceedings," 277.
[79] Welch, "Aiken's Program," 164.

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